Site-conditions map for Portugal based on VS measurements: methodology and final model

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ABSTRACT

In this paper we present a statistically significant site-condition model for Portugal based on shear-wave velocity (VS) data and surface geology. We also evaluate the performance of commonly used Vs30 proxies based on exogenous data and analyze the implications of using those proxies for calculating site amplification in seismic hazard assessment.

The dataset contains 161 Vs profiles acquired in Portugal in the context of research projects, technical reports, academic thesis and academic papers. The methodologies involved in characterizing the Vs structure at the sites in the database include seismic refraction, multichannel analysis of seismic waves and refraction microtremor. Invasive measurements were performed in selected locations in order to compare the Vs profiles obtained from both invasive and non-invasive techniques. In general there was good agreement in the subsurface structure of Vs30 obtained from the different methodologies.

The database flat-file includes information on Vs30, surface geology at 1:50.000 and 1:500.000 scales, elevation and topographic slope and based on SRTM30 and SRTM3 topographic datasets.

The procedure used to develop the site-conditions map is based on a three-step process that includes defining a preliminary set of geological units based on the literature, performing statistical tests to assess whether or not the differences in the distributions of Vs30 are statistically significant, and merging of the geological units accordingly. The dataset was, to some extent, affected by clustering and/or preferential sampling and therefore a declustering algorithm was applied. The final model includes three geological units: 1) Igneous, metamorphic and old (Paleogene and Mesozoic) sedimentary rocks; 2) Neogene and Pleistocene formations, and 3) Holocene formations.

The evaluation of proxies indicates that although both geological analogues and topographic slope are in general unbiased, the latter shows significant bias for particular geological units and subsequently for some geographical regions.

DATABASE

- Vs30 data
  - Vs depth data was both acquired in the context of projects SCENE and NEFITAG and gathered from the literature.
  - The database includes seismic refraction depth sections, MASW profiles, ReMi profiles and seimic cone penetrometer profiles.
  - Multi-method analysis performed in selected sites indicate compatible depth structures and Vs30 values.
- Geology
  - Geological classification of sites was performed using the 1:50.000 scale national geological maps.
  - Few sites for which no such scale map exists have bee classified using the 1:200.000 or the 1:500.000 scale maps.
- Topographic slope data
  - The topographic slope was calculated using the GMT grdgradient function on the SRTM digital elevation datasets at both 30 and 3 arcsec of resolution.
- Declustering
  - The dataset exhibited clustering or preferential sampling characteristics.
  - The declustering analysis applied indicated that only P1 was significantly affected by clustering.
  - A declustered version of F1 was subsequently used in the analysis.

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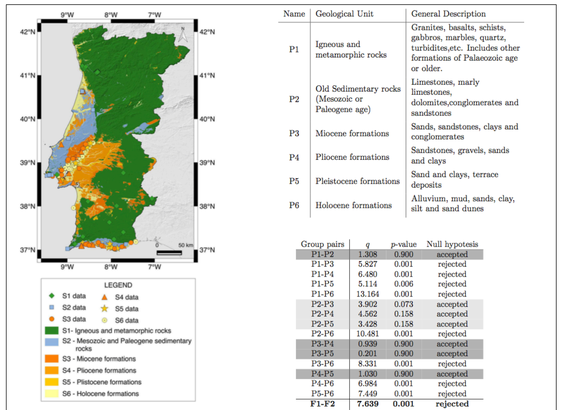
METHODOLOGY

Geology-based VS30 model based on a 3-step iterative procedure

- Preliminary model

  Model of geologically derived units based on literature (e.g., Wills and Clahan, 2006); Distributions of log Vs30 for each unit;
- Statistical tests

  Anova followed by Tukey HSD test the null hypothesis that the data from different units come from a common distribution;
- Merge geological defined units for which the differences are not statistical significant at a 5% confidence level;



Name	Geological Unit	General Description
P1	Igneous and metamorphic rocks	Granites, basalts, schists, gabbros, marbles, quartz, turbidites,etc. Includes other formations of Palaeozoic age or older.
P2	Old Sedimentary rocks (Mesozoic or Paleogene age)	Limestones, marly limestones, dolomites,conglomerates and sandstones
P3	Miocene formations	Sands, sandstones, clays and conglomerates
P4	Pliocene formations	Sandstones, gravels, sands and clays
P5	Pleistocene formations	Sand and clays, terrace deposits
P6	Holocene formations	Alluvium, mud, sands, clay, silt and sand dunes

Group pairs	q	p-value	Null hypotesis
P1-P2	1.308	0.900	accepted
P1-P3	5.827	0.001	rejected
P1-P4	6.480	0.001	rejected
P1-P5	5.114	0.006	rejected
P1-P6	13.164	0.001	rejected
P2-P3	3.902	0.073	accepted
P2-P4	4.562	0.158	accepted
P2-P5	3.428	0.158	accepted
P2-P6	10.481	0.001	rejected
P3-P4	0.939	0.900	accepted
P3-P5	0.201	0.900	accepted
P3-P6	8.331	0.001	rejected
P4-P5	1.030	0.900	accepted
P4-P6	6.984	0.001	rejected
P5-P6	7.449	0.001	rejected
F1-F2	**7.639**	**0.001**	**rejected**
F1-F3	**14.987**	**0.001**	**rejected**
F2-F3	**9.969**	**0.001**	**rejected**

FIGURE 1

Geographic distribution of the database (left); lithological description of the preliminary set of geologically defined units (top right); and results of the Tukey HSD test (bottom right). The null hypothesis is rejected for p>0.05).

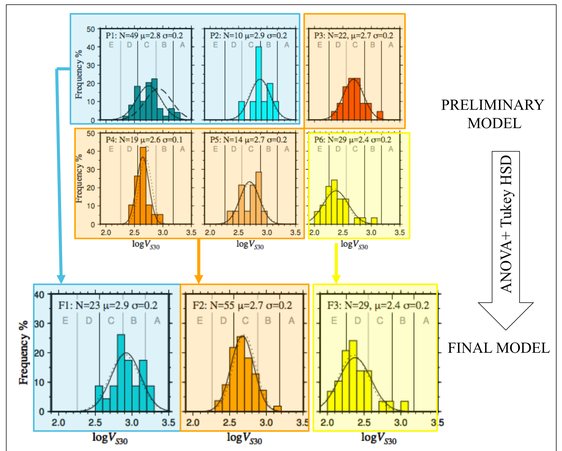


FIGURE 2

Normalized frequency distributions for log Vs30c, sorted by the geologically defined units for both the preliminary model (top) and the final model (bottom). The solid line shows the corresponding fitted normal distributions with mean μ and standard deviation σ. The dotted lines correspond to the fitted normal distributions for VS30z.

RESULTS

Testing correlations with topographic slope for refining the model

- Topographic slope has been often correlated with Vs30 in the literature (e.g, Wald and Allen, 2007, Thompson et al.,2014, Stewart et al (2014)
- The correlation between topographic slope and Vs30 is poor for the full dataset (Figure 3). However, for F3 sites (Holocene formations), there is some evidence of correlation between those variables, in particular for the SRTM3 DEM.
- A t-test procedure indicates that the differences between log Vs30 distributions of the two Holocene sets sorted by SRTM3-based topographic slope classes are statistically significant. However the data sets are very limited and the statistical power of the test is low. More data needs be acquired before including this variable in the model with confidence.

Final geology-based Vs30 model For Portugal

- The final model consists of three geologically defined units characterized by Vs30 distributions characterized and illustrated in Figure 4.

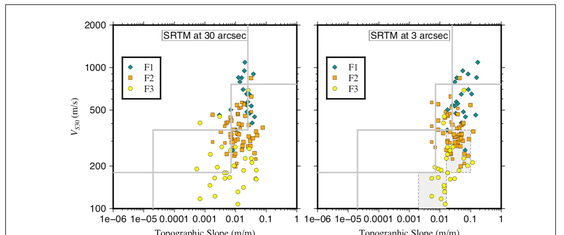
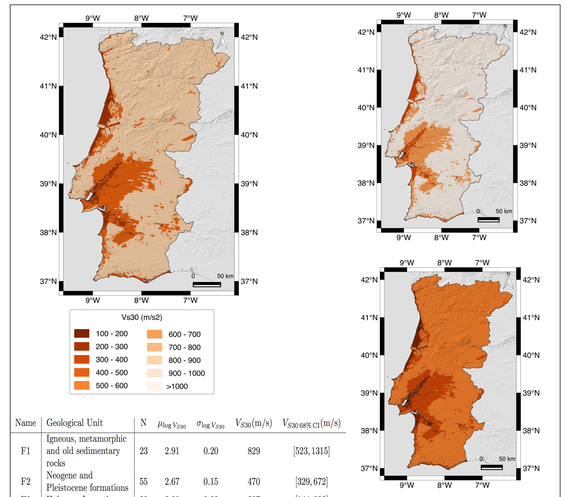


FIGURE 3

Vs30 as a function of slope sorted by the final set of geologically defined units. The boxes outlined in gray represent the VS30-slope class correlations proposed by Wald and Allen (2007) for stable continental regions. The boxes outlined with dashed lines (right) represent tentative VS30-slope class correlations for Holocene data in this study.



Name	Geological Unit	N	$\mu_{\log V_{S30}}$	$\sigma_{\log V_{S30}}$	V_{S30}(m/s)	$V_{S30\,68\%\,CI}$(m/s)
F1	Igneous, metamorphic and old sedimentary rocks	23	2.91	0.20	829	[523, 1315]
F2	Neogene and Pleistocene formations	55	2.67	0.15	470	[329, 672]
F3	Holocene formations	29	2.38	0.22	237	[144, 392]

FIGURE 4

Final Vs30 model; log-averaged VS30 value (a); upper (b) and lower limits of the 68% confidence interval for the VS30 distribution;

DISCUSSION

Peformance of models based on exogenous Vs30 data

- We analyzed the residuals between the Vs30 values measured and those predicted
  - By the he topographic-based Vs30 global model of Allen and Wald (2007)
  - By the geological analogue model as implemented by Silva et al. (2014), based on the geology-based Vs30 model of Wills and Claham (2006).
- The residuals (Figure 5) show that:
  - Both methods show fairly unbiased total residuals.
  - The topographic-slope model is biased towards lower values of Vs30 for F1 sites and it is biased towards higher values of Vs30 for F3 sites.
  - The residual's distribution shows clear linear trends with the independent variable for the topographic slope-based model.
  - The geological analogue model is biased towards low values of Vs30 for the F2 unit highlighting the difficulties associating with choosing a proper geological analogue from a different geographical region.

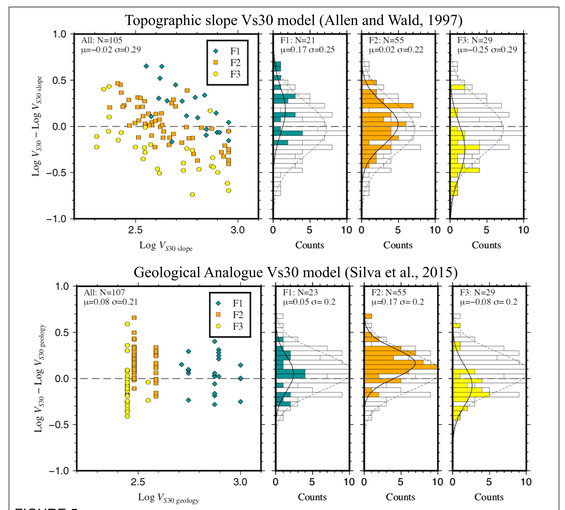


FIGURE 5

Residual distributions of log VS30 with log VS30 values predicted by a) the topographic slope model (see text for details), and b) from the geological analogue method

CONCLUSIONS

- We present a geology-based VS30 model for Portugal which includes three geological categories: F1 - Igneous, metamorphic, and sedimentary rocks of Mezosoic or Paleogene age; F2 - Neogene and Pleistocene Formations; and F3 - Holocene Formations. The logVS30 distributions pertaining to each geologic category are statistically significantly different from each other.
- We find that the correlation between slope and VS30 is in general poor, such as reported by Lemoine et al. (2012) for other stable continental regions within Europe.
- For Holocene sites (F1) there is some correlation between Vs30 and slope SRTM3-based topographic slope. However, since our dataset is limited, we feel that more data is required in order to use the relationship with confidence.
- Models based on exogenous Vs30 data are significantly biased for some geologic units.
- The topographic slope-based Vs30 global model by Allen and Wald (2007) shows residuals that display a linear trends with slope, indicating that the correlation between slope and Vs30 is weaker for our dataset that what is assumed by the model.